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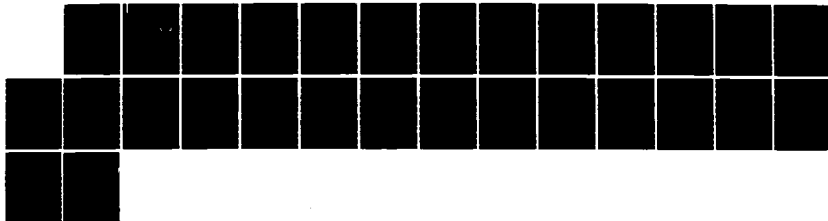
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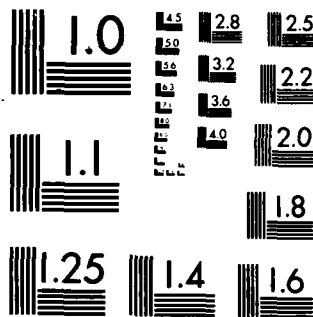
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**FOULING SETTLEMENT AT HMAS STIRLING (COCKBURN
SOUND, WESTERN AUSTRALIA) - A REVIEW**

John A. Lewis

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DEPARTMENT OF DEFENCE
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John A. Lewis

ABSTRACT

10/11/84
The settlement of marine fouling organisms at HMAS STIRLING has been subject to a number of studies between 1976 and 1984. Results from these are reviewed to assess the continuity and seasonality of settlement during this period. Most organisms, with the exception of Mytilus edulis which has a well-defined winter settlement, appear capable of settling throughout the year. However, the magnitude of settlement varies, both with time and between study sites. This variation is attributed to the proximity, abundance and reproductive state of brood populations, and the success of larval transport between brood sites and test panels. (Studies)

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SECURITY CLASSIFICATION OF THIS PAGE

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DOCUMENT CONTROL DATA SHEET

REPORT NO. MRL-R-995	AR NO. AR-004-438	REPORT SECURITY CLASSIFICATION Unclassified
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TITLE

Fouling settlement at HMAS Stirling (Cockburn Sound,
Western Australia) - a review

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REPORT DATE

May, 1986

TASK NO.

NAV 96/115

SPONSOR

Navy

FILE NO.

G6/4/8-3022

REFERENCES

31

PAGES

26

CLASSIFICATION/LIMITATION REVIEW DATE

CLASSIFICATION/RELEASE AUTHORITY
Superintendent, MRL
Organic Chemistry Division

SECONDARY DISTRIBUTION

Approved for Public Release

ANNOUNCEMENT

Announcement of this report is unlimited

KEYWORDS

Fouling organisms
Western Australia

HMAS Stirling

COSATI GROUPS 0603

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The settlement of marine fouling organisms at HMAS STIRLING has been subject to a number of studies between 1976 and 1984. Results from these are reviewed to assess the continuity and seasonality of settlement during this period. Most organisms, with the exception of Mytilus edulis which has a well-defined winter settlement, appear capable of settling throughout the year. However, the magnitude of settlement varies, both with time and between study sites. This variation is attributed to the proximity, abundance and reproductive state of brood populations, and the success of larval transport between brood sites and test panels.

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FOULING SETTLEMENT AT HMAS STIRLING (COCKBURN SOUND,
WESTERN AUSTRALIA) - A REVIEW

1. INTRODUCTION

✓ In 1978 the RAN sited a paint test raft at HMAS Stirling in Cockburn Sound, Western Australia. In accord with Defence policy, Navy Office applied to have this raft registered by the National Association of Testing Authorities (NATA). Part of the requirement for registration was that the raft and raft site met the criteria specified in Australian Standard 1580 Test Method 481.5 [1]. The biological criterion specified by this test method is that "Settlement of the larva of fouling organisms shall take place throughout the year". It was therefore necessary to establish that this criterion was satisfactorily met. (4c p 11)

By definition, settlement is the point when a planktonic larva or spore first cements itself to the surface [2]. To measure settlement and ensure that no post-settlement mortality takes place, newly-settled organisms would need to be censused at frequent intervals; for example, at intervals of one hour [3] or one day [2]. Many larvae and spores are too small to easily detect at the time of settlement and, particularly in studies of multispecies fouling communities, frequent censusing may be logistically impractical. Recruitment, or the number of organisms surviving to detectable size after a certain period (often one month), is therefore widely used as a measure of settlement. Although few studies have actually measured settlement, indications are that the density of settlers can be inferred from the density of recruits [2]. In this review such a relationship is assumed to exist and reported recruitment will be considered to represent settlement.

The settlement of marine macrofouling at HMAS STIRLING has been subject to study for much of the period between 1976 and 1984 [4-11]. However, these studies were not all conducted by the same individuals or within the same organisations. As a result, methods of data collection and the format of data presentation varied. This report collates the available data on monthly settlement of fouling larvae in a uniform format. Characteristics of settlement at the site can then be more readily assessed and trends in the seasonality of settlement of particular groups identified.

2. DATA SOURCES

The following data sources have been used:

- (a) Chalmers, University of Western Australia (4,5)
- (b) Dunstan, MRL [6-8]
- (c) Lewis, MRL [9,10], and
- (d) Carnell, WAGCL [11].

The sites, materials and assessment methods used in these studies are summarised in Table 1. In all studies test panels were immersed for periods of approximately one month, then removed and replaced with new panels. Fouling settlement was generally assessed under a stereomicroscope in the laboratory, which enabled both the newly-settled larvae and older juvenile invertebrates to be counted.

3. DATA PRESENTATION

The aim of this report was to identify general characteristics of fouling settlement, rather than characteristics for individual species. Moreover, data for individual species were not consistently available, partly due to the difficulties of identifying newly-settled larvae to species level. Data were therefore pooled into six multispecies groups: total counts, tubeworms, barnacles, molluscs, bryozoans and ascidians. A list of the common species recorded at HMAS STIRLING is given in Appendix 1.

The density of settlement (number/m²) of each group was assessed as the sum of densities of the component taxa. To determine density, counts were made of all individuals or colonies within a specified area of panel surface. Monthly densities were standardised to a 28 day period and settlement expressed as number/m²/month (28 days). For graphical presentation, counts were transformed using the logarithmic transformation, $x = \log(n+1)$, which permits all values to be conveniently presented on a uniform scale.

4. RESULTS

4.1 Data Reliability

Chalmers [4] reported only the abundance of the six most numerous taxa (*Mytilus edulis*, Barnacle spp., *Anomia descripta* (= *A. trigonopsis*), *Ostrea* sp., *Bugula* spp. and *Spirorbis* sp.). In this review, the abundances of these six taxa have been used to compute total species group densities and some underestimation will have resulted. For the barnacles, molluscs and tubeworms this will be small as the most numerous organisms are included in

TABLE 1

Details of methods used in the various studies

Source	Period	Site	Panels	Depth	Assessment Method
Chalmers	12/5/76- 16/5/77	Escort Wharf	Asbestos 300 mm x 300 mm x 5 mm	approx. 2 m	counts within the central 25 cm square on the south-facing side of panels
Dunstan	3/2/77- 21/11/79	Submarine Wharf	Black PVC 300 mm x 150 mm x 3 mm	approx. 3 m	counts within two 130 mm x 30 mm transects 70 mm from the top and bottom on each side of panels
Lewis 1a	28/7/78- 28/6/79	Raft	Grey PVC 300 mm x 150 mm x 6 mm	approx. 1 m	counts within a 100 mm square on the north-facing side of panels
Lewis 1b	31/5/79- 29/5/80	" "	Black PVC 300 mm x 150 mm x 3 mm	" "	" " " " " "
Carnell	19/5/81- 4/2/83, 14/9/83- 15/3/84	" "	Black acrylic 300 mm x 150 mm x 4.5 mm	3 panels 0.5 m, 1 m, 1.5 m	counts within a 100 mm square on the north-facing side of panels, monthly counts averaged for panels assessed
Lewis 2	14/10/83- 16/7/84	" "	Black acrylic 170 mm x 150 mm x 4.5 mm	2 panels 0.5 m, 1.5 m	counts within a 100 mm square on the north-facing side of panels

Chalmers' list. However, several bryozoan species apart from the *Bugula* spp. are known to occur frequently at the site and total bryozoan densities will therefore be conservative. No ascidian species is in Chalmers' list so no data on ascidian settlement is available for this period.

Methods used at WAGCL prior to December 1983 are also known to have underestimated larval settlement, by up to 50% in some instances [11].

4.2 Total Counts (Figure 2)

The larvae of fouling organisms settled throughout the study period and, for all but three panels exposed beneath the raft in 1978, the density of organisms exceeded 1000 per m². It is important to note that not all organisms present on a panel are included in density counts. Some, for example turf-like algae and hydroids, cannot be satisfactorily counted. Total counts therefore represent the summed density of countable organisms. This will be discussed further in Section 4.8.

Little meaning can be attached to trends observed in a data set summed over such a wide range of organism groups. Discussion of trends will therefore be confined to the individual groups.

4.3 Tubeworms (Figure 3)

Tubeworms, predominantly Spirorbid tubeworms, settled consistently throughout most of the study period and overall were the most abundant group of organisms. Maximum settlement tended to occur over the summer, although the month of peak settlement varied from November (in 1976) to February (in 1982).

During the period August 1978 - November 1979, when there were concurrent studies beneath the raft and Submarine Wharf, tubeworm settlement was initially lower at the raft site. However, by the end of this period, settlement trends at the two sites were similar.

4.4 Barnacles (Figure 4)

Barnacle settlement, predominantly by two species - *Balanus trigonus* and *B. variegatus*, was less consistent than tubeworm settlement but nevertheless occurred through most of the study period. From 1978 until 1982 the time of peak settlement occurred later each year, i.e. January 1977, March 1978, April 1979, May 1980, June 1981. The other obvious trend was the frequent reduction in settlement, to zero in some years, during spring or early summer.

Trends observed on the raft were similar to those under the Submarine Wharf.

4.5 Molluscs (Figure 5)

Two trends are evident in the settlement of the molluscs. The first is the massive winter peak in 1976, 1978 and 1979, due to settlement of the mussel *Mytilus edulis*. The second is the consistent low level settlement, during 1977-78 and 1983-84, of oysters (*Ostrea* sp.) and jingle shells (*Anomia trigonopsis*).

In 1978 and 1979 a peak in *Mytilus* settlement was detected on raft panels but not on panels from under the Submarine Wharf.

4.6 Bryozoans (Figure 6)

Bryozoan settlement was reasonably consistent under the Submarine Wharf for the period of that study, the only apparent trend being a reduction in spring. The variation in settlement at the raft site was much greater, with an apparent trend towards a bimodal settlement pattern with numbers declining in late summer or early autumn and spring.

Chalmers reported only *Bugula* settlement and, as a number of other bryozoans commonly settle at HMAS Stirling, this probably underestimates total bryozoan abundance.

4.7 Ascidiants (Figure 7)

Colonial ascidiants settled more abundantly than solitary species. Below the Submarine Wharf, ascidian settlement was reasonably consistent from early 1977 until May 1979, when numbers declined sharply, then recommenced in August of that year.

During the period of concurrent studies on the raft and below the Submarine Wharf, settlement was initially much lower on the raft but increased in early 1978 to show a similar settlement trend over autumn. After the reduction in settlement which occurred concurrently at both sites, recovery was delayed at the raft site and settlement did not recommence until November.

Settlement on the raft in early 1984 was much higher than at the same site during the 1981-82 study period.

4.8 Frequency vs. Density (Figure 8)

The disadvantages of density as an assessment of the overall abundance of fouling organisms have been discussed elsewhere [12] and frequency proposed as an alternate abundance measure for short-exposure test panels. Whereas density measures the number of individuals present within an area of panel surface, frequency is the probability of a species having settled within an area. The latter has been assessed by recording the presence or absence of each taxa within one hundred 5 mm x 5 mm squares

arrayed over the central 10 cm x 10 cm area of the panel. The number of presence scores gives the percentage probability of that taxa occurring in the assessment area.

Panels exposed at HMAS STIRLING from late 1983 onward have been assessed using both techniques and the results can be compared in Figure 8. The most obvious advantage of the frequency method is that all organisms, and not just those which settle as discrete individuals or colonies, can be assessed and their contribution to the fouling community compared on a single scale. Other less obvious advantages are the capacity of the method to assess the overall abundance of large spreading organisms and the decreased time involved in assessment when large numbers of organisms are present. Trends in density counts are also evident in the frequency results. Insufficient data are available at present to identify trends in settlement of those organisms only assessed by frequency.

5. DISCUSSION

5.1 Factors Controlling the Abundance of Settlement

The settlement of sedentary organisms on to hard substrata, and the magnitude of settlement, depends on:

- (a) the presence in the water of larvae competent to settle and their abundance,
- (b) the suitability of conditions for settlement, and
- (c) the suitability of the substratum.

The presence of larvae competent to settle depends on the proximity of breeding adults, survival of the planktonic larvae, and transport of the larvae from the brood population to the potential substratum. The timing and duration of the reproductive cycle varies greatly between species and reproductive maturation is governed by a multiplicity of factors such as food availability, water temperature and daylength. Some species reproduce all-year round whereas others release larvae only during well-defined seasons. The number of larvae released also varies between species.

The duration of the planktonic life stage, which varies considerably between species, governs the distance a larva can travel prior to settlement. Ascidian, bryozoan and tubeworm larvae settle and metamorphose within hours of release [13-16], and swimming-time may be as little as 10 minutes [17]. Alternatively, swimmers of the green alga *Enteromorpha* can remain motile for several days [18] and the larvae of barnacles and molluscs spend several weeks in the plankton [19-20]. Species with a short swimming-time will mostly settle close to their parents, but those with long swimming-times can, depending on water movements, travel considerable distances prior to settlement. The larvae of some species also move in small swarms [21], and

for these two substrata only a short distance apart may show very different settlement densities.

Water movement can have a considerable effect on larval settlement and many organisms will not settle when water velocity relative to the substrate exceeds a certain value. The critical speed for several species of barnacle can be as low as 1 knot but, on the other hand, sub-critical speeds are known to stimulate the settlement of barnacle cyprids [20]. Other environmental factors may also influence settlement as, for example, the stimulatory effect low salinities can have on settlement of the hydroid *Tubularia* and the barnacle *Elminius* [20].

When larvae are ready to settle most do not attach to the first substrate they contact but show selectivity in choosing an attachment site. The suitability of a substrate can be governed by its colour [22], polarity [23], texture [24], orientation [25], illumination [17], or the presence of bacterial films [26], conspecifics [21] or other species [27].

5.2 Fouling Settlement at HMAS STIRLING

5.2.1 Variation between sites

Some variation in settlement characteristics was evident between the Submarine and Escort Wharf sites and the raft site. Similar methods were used at all sites with dark-coloured panels suspended vertically below the water surface. At the wharf sites, however, panels were continuously shaded, whereas panels below the raft were in direct sunlight. The settlement of algae, which require light for photosynthesis, was therefore inhibited on panels from below the wharves but increased settlement of those organisms which prefer shaded surfaces would be expected. The larvae of many benthic invertebrates, including bryozoans, are known to be photonegative prior to settlement [28-29] and this would explain the generally higher and more consistent settlement of bryozoans under the Submarine Wharf (Figure 6).

During the period when concurrent studies were in progress on the raft and beneath the Submarine Wharf, ascidian, bryozoan and tubeworm settlement were initially lower on the raft but subsequently increased to similar levels (Figures 3,6,7). Moreover, and this is particularly obvious for the ascidians (Figure 7), when subsequent drops in settlement took place, recovery was much slower on the raft. Similar trends did not occur for the barnacles or molluscs (Figures 4,5).

This difference can be explained by the proximity of the two sites to brood populations and the length of time fouling larvae swim prior to settlement. The wharves at HMAS STIRLING are supported on numerous concrete piles covered by substantial populations of many of the species found on the test panels. Test panels suspended below the wharves are therefore within easy reach of those fouling larvae with short swimming times; namely ascidians, bryozoans and tubeworms. However, no similar fouling populations occur adjacent to the raft site, the only hard substrata being the rock causeway which does not support a typical fouling community. Larvae settling

on panels below the raft must therefore come from the raft itself or have swum from distant brood populations. The number of short-swimming species available to settle will diminish with increasing distance from the brood populations so initial settling rates will be low until reproductive colonies can establish on the raft.

As a consequence, when the test raft is cleaned of fouling, settlement rates of ascidians, tubeworms and bryozoans are likely to be reduced until fertile colonies can reestablish on the raft pontoons. However, this would not apply to species whose larvae have long-swimming times (ie. barnacles, bivalve molluscs) which enable them to be independent of local colonies.

5.2.2 Temporal variations in settlement

Mytilus edulis was the single common species at HMAS STIRLING to settle only during a well-defined settlement season. Reproduction in *Mytilus* is controlled by either food supply [30], water temperature [31] or both. Thus in Cockburn Sound gonad development begins when the water temperature drops below 21°C which leads to spawning from mid-July to September [31]. However, the annual settlement is not always recorded during short-term panel studies. *Mytilus* settles preferentially on filamentous substrates and this condition is not found on newly immersed panels unless they have previously been colonised by other organisms. Dunstan [7] found juvenile *Mytilus* to be absent from a newly immersed panel but present in abundance on a panel previously colonised by other species.

Unlike *Mytilus*, other organism groups at HMAS STIRLING appear able to settle throughout the year, though their abundance varies. Such variation would reflect the abundance of breeding adults in brood populations, and the breeding success of those adults as controlled by food supply and environment. Water movement could also affect settlement. For example, a period of offshore winds would move all larvae of a long-swimming organism such as a barnacle away from the area and reduce the observed settlement for that time. This may account for some of the seemingly irregular drops in organism abundance.

6. CONCLUSIONS

- (a) Marine fouling organisms settle throughout the year on subtidal surfaces at HMAS STIRLING. The major organisms, with the exception of the mollusc *Mytilus edulis*, appear capable of settling at any time but the magnitude of settlement can vary, both within and between sites.

- (b) Organisms whose larvae have short swimming times exhibited periods of reduced settlement at the raft site. In part, this could be due to the location of the raft away from established fouling communities. Such organisms (tubeworms, bryozoans and ascidians) would largely depend on colonies established on the raft pontoons as brood populations. If these were removed, either naturally or artificially, settlement on panels below the raft would be reduced until breeding adults could re-establish.
- (c) The settlement of organisms whose larvae spend longer periods in the plankton (eg. barnacles and molluscs) is less dependent on closely-located brood populations, but would be influenced by water movements into and out of the region.
- (d) Settlement of *Mytilus edulis* is a regular winter phenomenon in Cockburn Sound but larvae do not settle on newly immersed panels unless the panels have been previously colonised by filamentous organisms.

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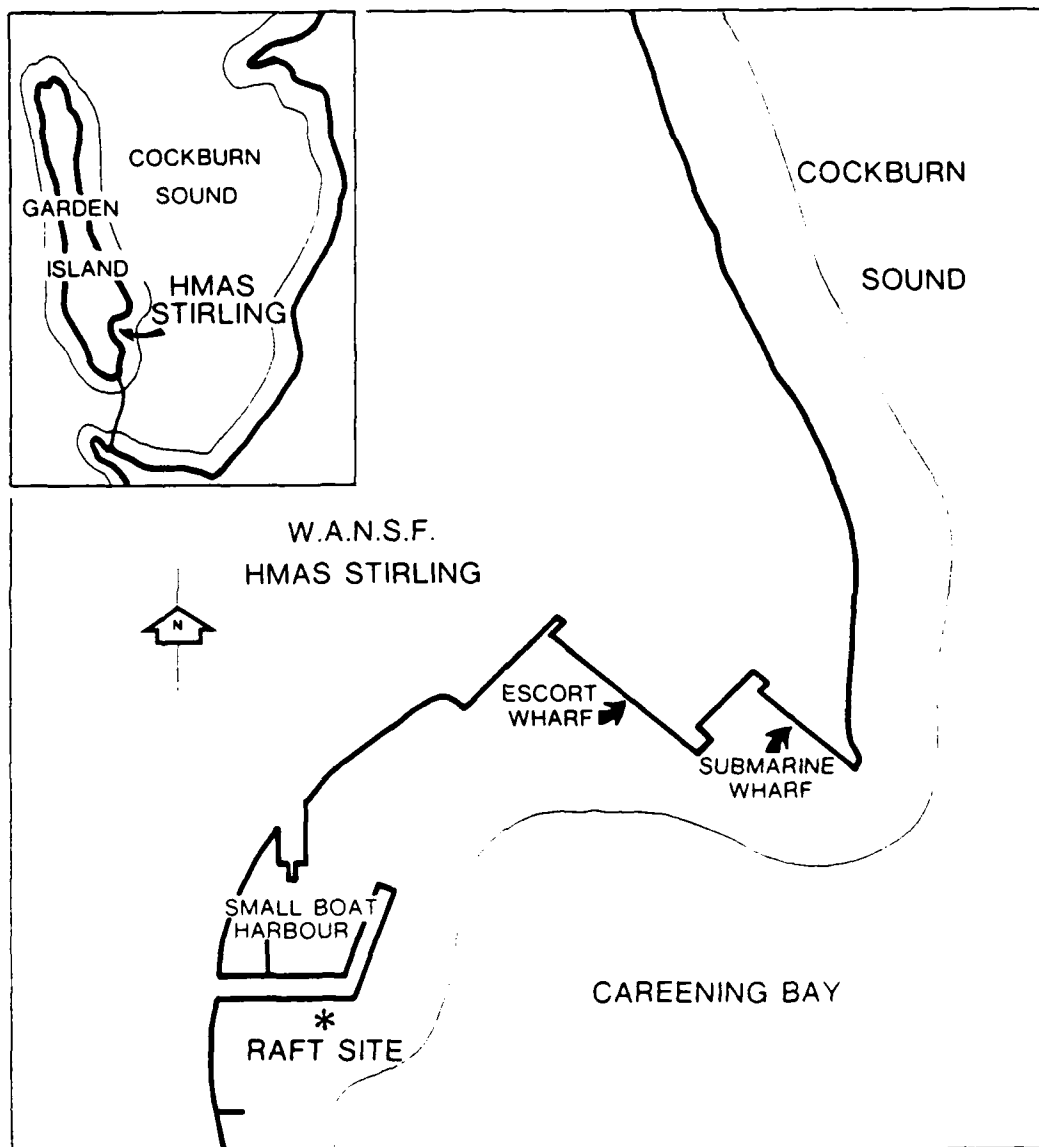


FIGURE 1. Map of HMAS STIRLING showing the location of the study sites

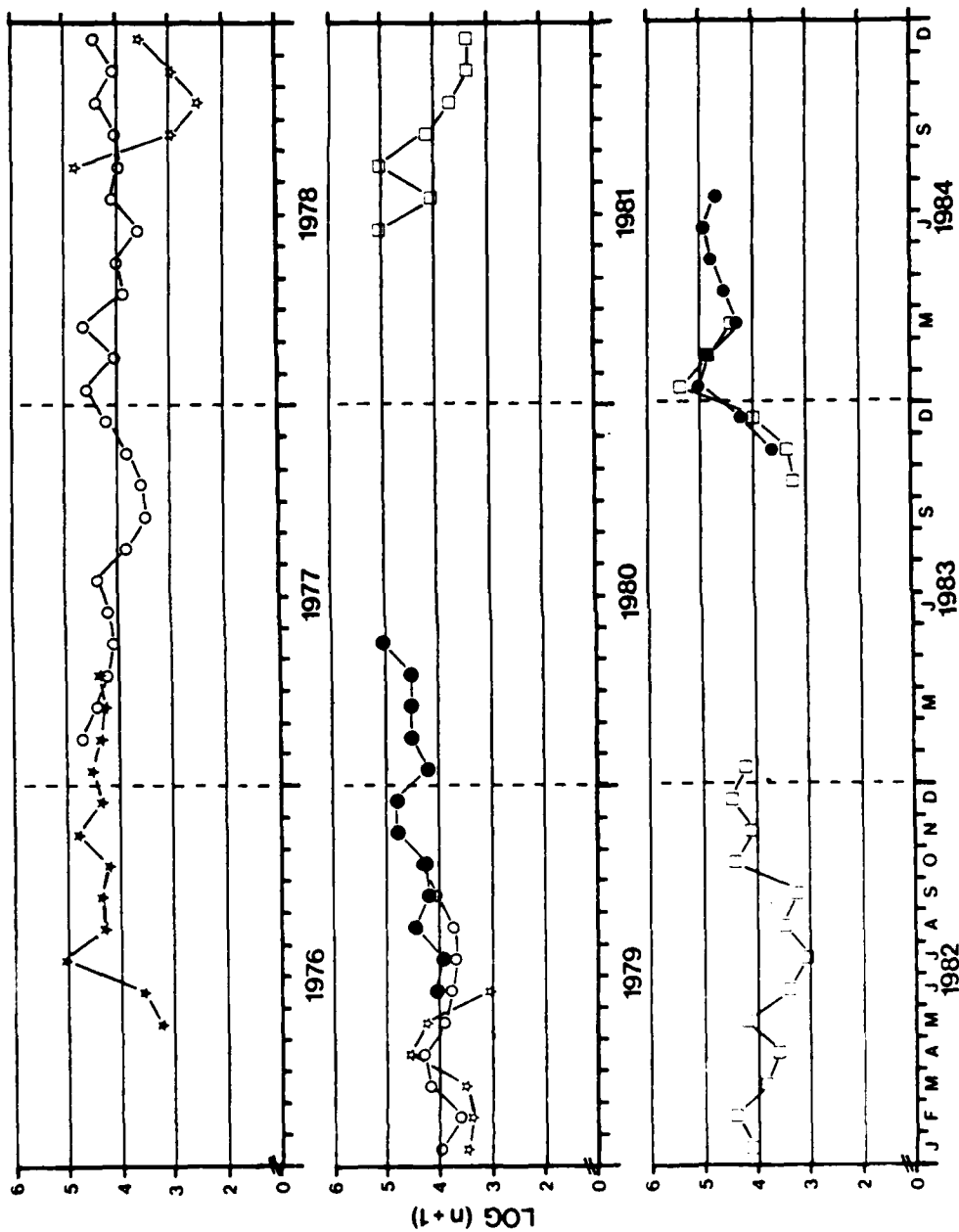


FIGURE 2. Overall recruitment of countable organisms ($\log(n+1)$), where $n = \text{no.}/\text{m}^2/28 \text{ days}$ to panels immersed for periods of one month.

(Closed stars, Chalmers⁴; open circles, Dunstan^b; open stars, Lewis 1a^c; large closed circles, Lewis 1b^c; open squares, Carnell^c; small closed circles, Lewis 2^c
 a Escort Wharf, b Submarine Wharf, c raft; refer to Table 1 for other details)

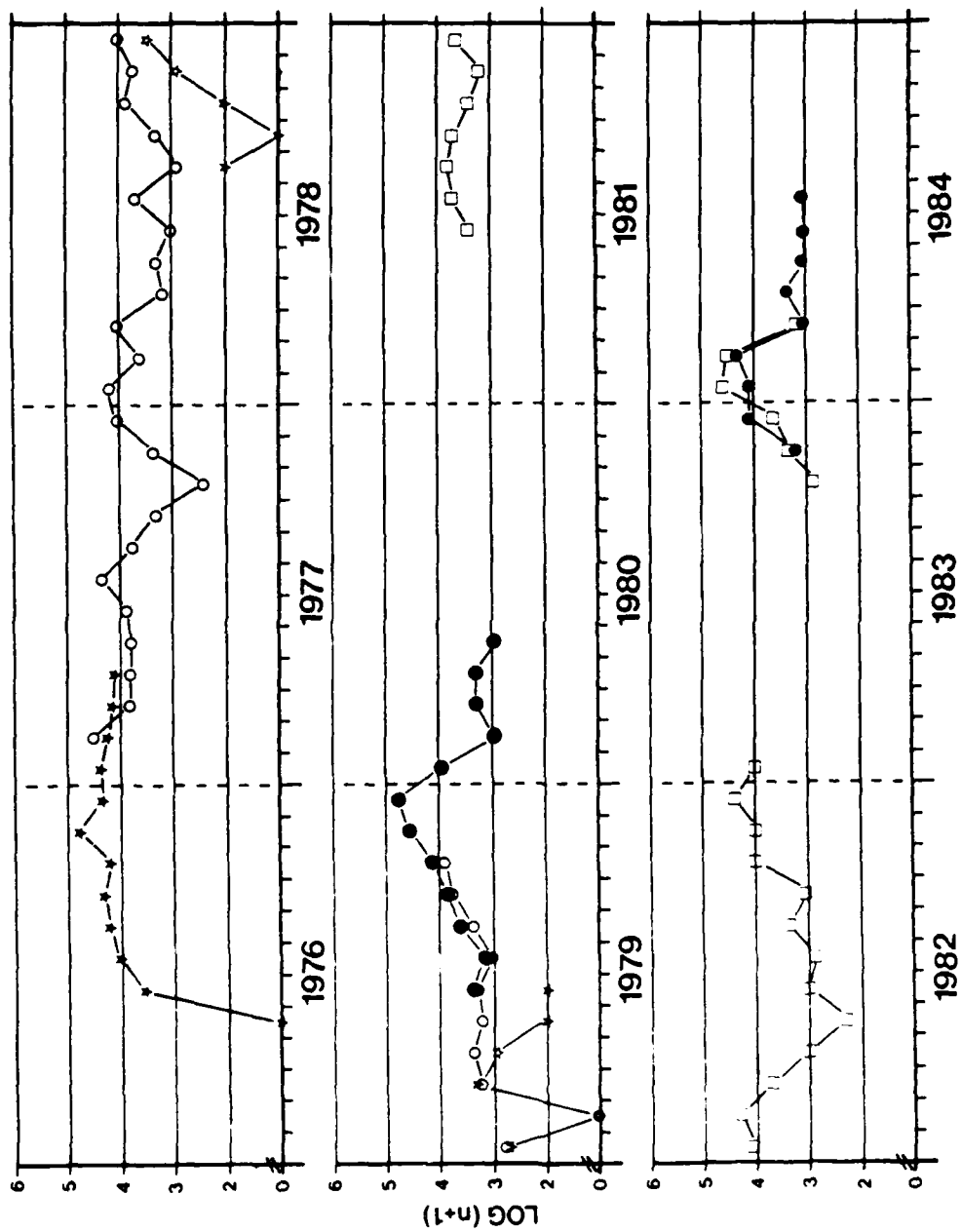


FIGURE 3. Monthly recruitment of tubeworms through the study period.

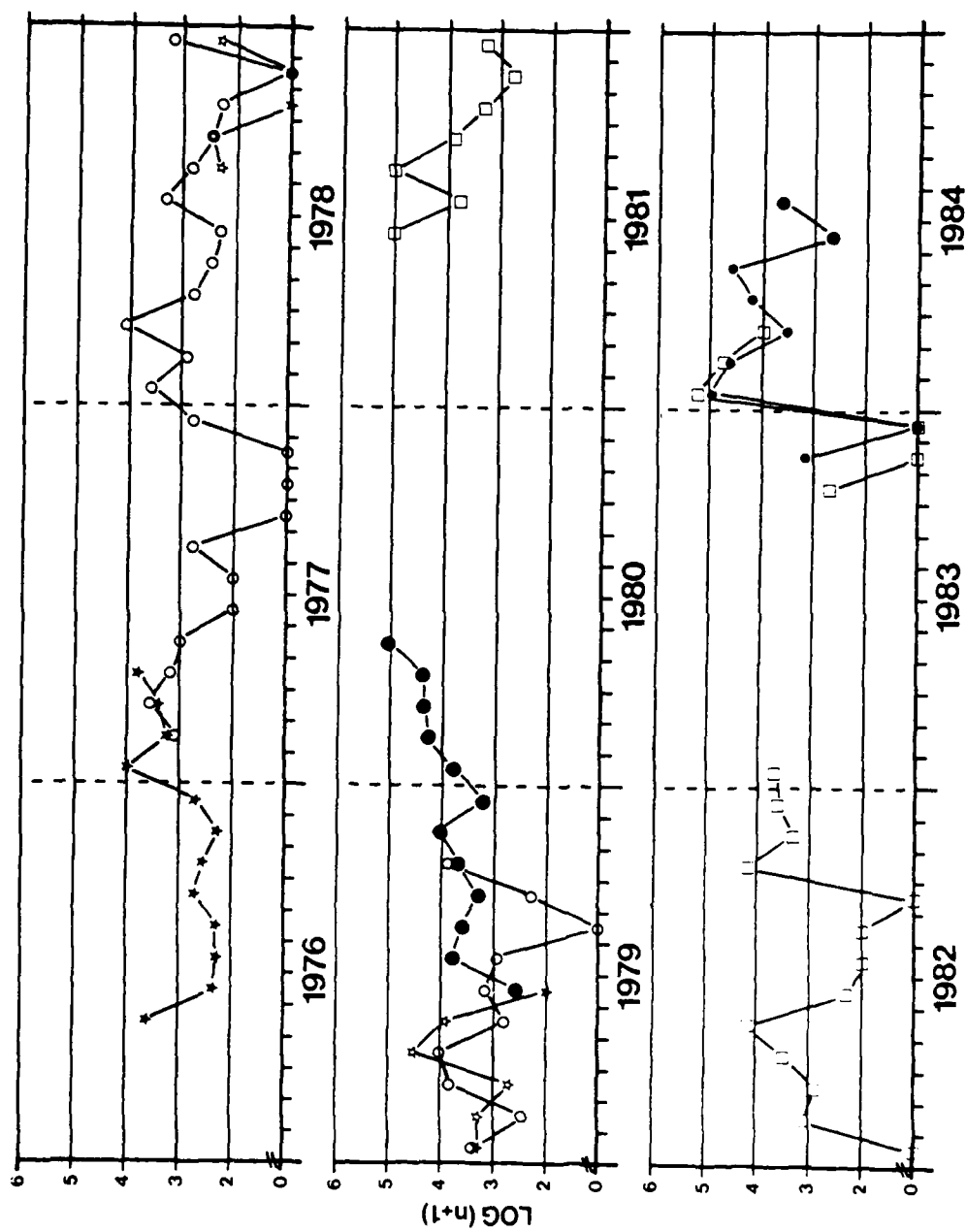


FIGURE 4. Monthly recruitment of barnacles through the study period.

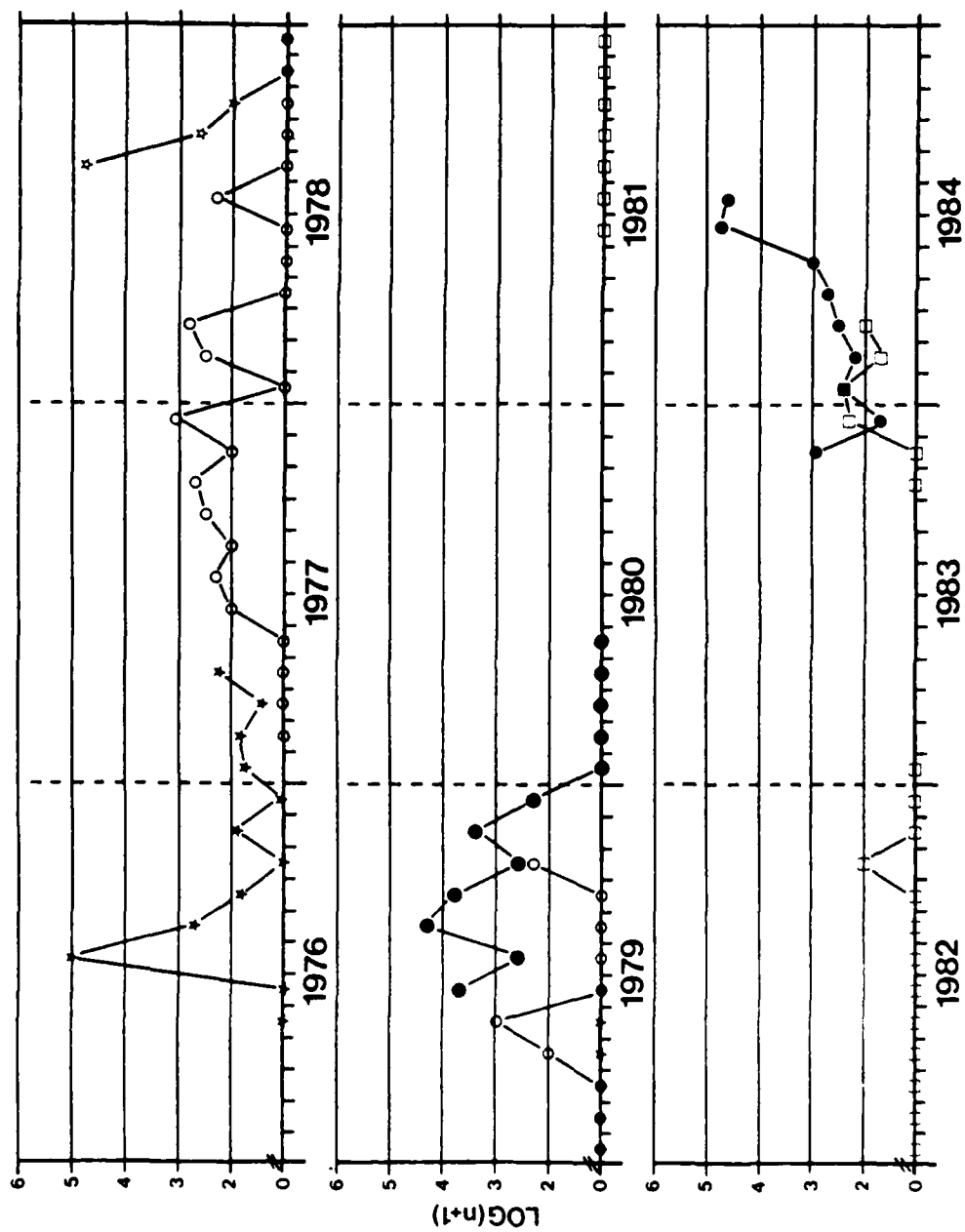


FIGURE 5. Monthly recruitment of molluscs through the study period.

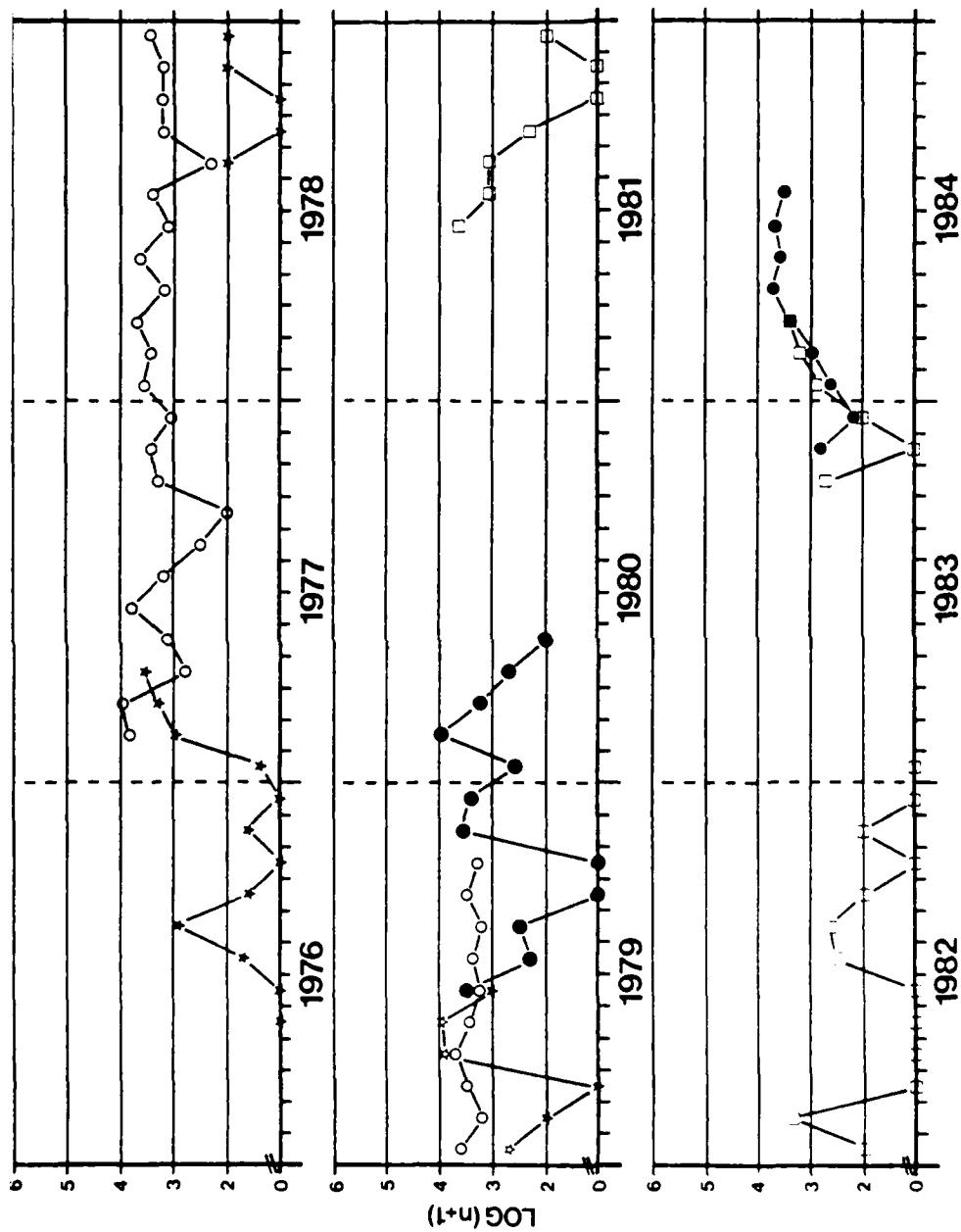


FIGURE 6. Monthly recruitment of bryozoans through the study period.

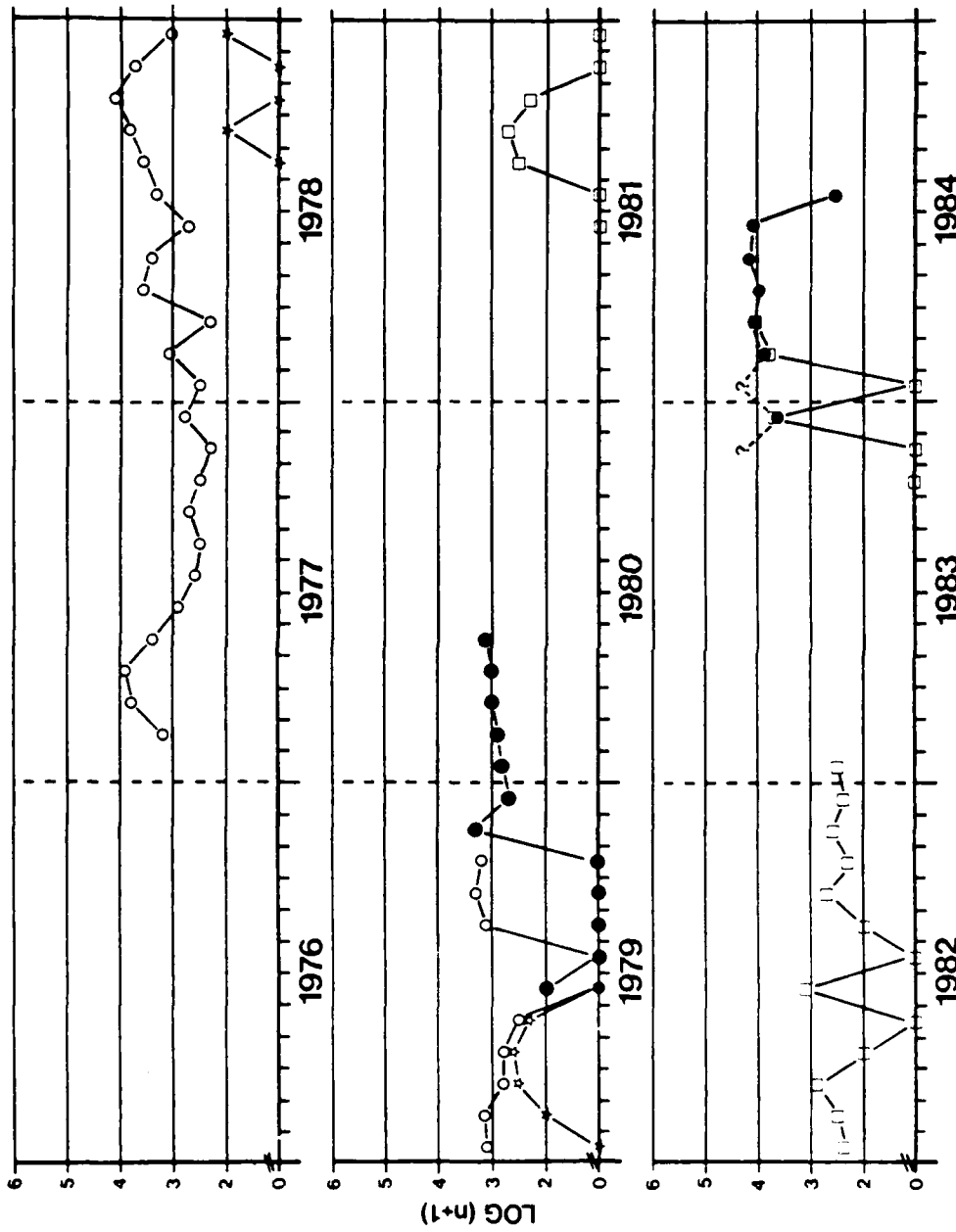


FIGURE 7. Monthly recruitment of ascidians through the study period.

? during these months abundant ascidians were present as merging and overlapping colonies which could not be discretely counted.

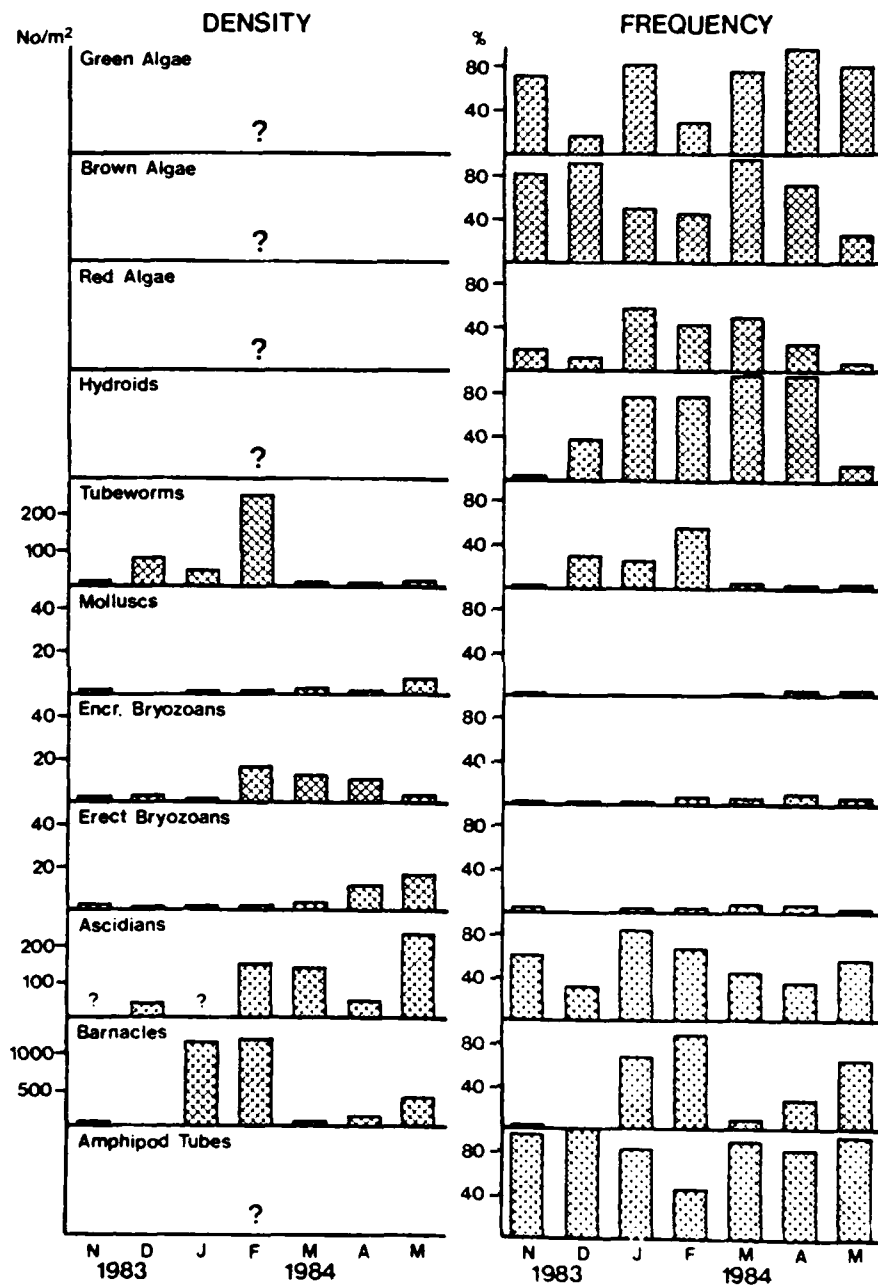


FIGURE 8. Comparison of fouling abundance as assessed by density and frequency methods. Assessments are for the north-facing side of panels immersed at a depth of 0.5 m below the raft.

APPENDIX 1

List of the Common Fouling Species recorded at HMAS STIRLING

* = prominent species

Additional information can be found in:

Lewis, J.A. (1982). "A guide to the principal marine fouling organisms, with particular reference to Cockburn Sound, W.A." Report MRL-R-858, Materials Research Laboratories, Melbourne.

ALGAE

CHLOROPHYTA

- **Enteromorpha compressa* (L.) Grev.
- **Ulva rigida* C.Ag.
- Bryopsis plumosa* (Huds.) C.Ag.

PHAEOPHYTA

- **Ectocarpus* spp.
- **Giffordia irregularis* (Kuetz.) Joly

RHODOPHYTA

- **Polysiphonia subtilissima* Mont.
- **P. infestans* Harv.
- **Polysiphonia* sp.
- Hypnea* sp.
- Jania* sp.
- Corallinaceae* sp.
- Centroceras clavulatum* (C.Ag.) Mont.
- Ceramium* sp.
- Dasya* sp.

INVERTEBRATES

SPONGES (Porifera)

- Scypha ciliata* (Fabricius)

HYDROIDS (Cnidaria, Hydrozoa)

- **Tubularia ralphi* Bale
- **Obelia* sp.
 - O. bidentata* Clark
 - Hydractiniid* sp.
 - Campanularia johnstoni* Alder

TUBEWORMS (Annelida, Polychaeta)

- **Serpula vermicularis* Linnaeus
- **Filograna implexa* Berkeley
- **Janua pagenstecheri* (Quatrefagus)
- **Pileolaria militaris* Claparede
- Polydora* sp.
- Hydroides elegans* (Haswell)
- H. brachycantha* Rioja
- Galeolaria hystrix* (Morch)
- Pomatoceros taeniatus* (Lamarck)

MOLLUSCS (Mollusca)

- **Mytilus edulis* Linnaeus
- **Anomia trigonopsis* Hutton
- **Ostrea folium* Linnaeus
 - O. angasi* Sowerby
 - Hiatella australis* (Lamarck)

BARNACLES (Crustacea, Thoracica)

- **Balanus trigonus* Darwin
- **B. variegatus* Darwin
 - B. amphitrite amphitrite* Darwin

AMPHIPODS (Crustacea, Amphipoda)

Gammarid spp.

BRYOZOANS (Bryozoa)

- **Watersipora arcuata* Banta
- **W. subovoidea* (d'Orbigny)
- **Schizoporella errata* (Waters)
- **Bugula neritina* Linnaeus
- **B. stolonifera* Ryland
 - B. flabellata* (Thompson)
 - Tricellaria* sp.
 - Microporella* sp.
 - ?*Umbonulid* sp.

ASCIDIANS (Chordata, Ascidiacea)

**Trididemnum* sp.

*Unid. colonial spp.

Ascidia aspersa (Muller)

Microcosmus claudicans Savigny

Corellid sp.

Molgula batemani Kott

Styela irma (Hartmeyer)

Botrylloides leachii (Savigny)

Symplegma viride Herdmann

END

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